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Hzard and risk assessment of pollution on the groundwater resources and residents' health of Salfit District, Palestine

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ABSTRACT

Study region: The study area is the Salfit District which is located in the northern part of the West Bank of Palestine. This district is located on the outcrops and recharge areas of the karstified dolomitic limestone aquifers of the study area.
Study focus: As these aquifers are the main sources of drinking water for the residents of the district, this paper aims at evaluating groundwater pollution and assessing the vulnerability, hazards and risks of pollution on groundwater resources and on the residents' health.
New hydrological insights for the region: There are many pollutants in the Salfit's aquifer recharge area and thus percolating and polluting the groundwater aquifers. Using a Durov diagram, the sources of water proved to be polluted and, therefore, the health of the residents of Salfit District is directly threatened. A hazard map was developed to classify all polluting activities in the district. Microbiological analysis of the drinking water revealed higher levels of total and fecal *Coliforms*. The high incidence rate of water related diseases is an indication of the drinking water pollution. This paper contains research findings and policy recommendations to help Salfit District alleviate health and pollution problems associated with this vital resource of groundwater. In addition, Salfit governorate is encouraged to begin addressing the institutional issues and improving public awareness.

1. Introduction

There is an increasing demand for groundwater resources in the agricultural sector and for domestic use in Palestine. It is the main source of drinking water for the majority of the population in the West Bank. Moreover, because the aquifers in the West Bank are karstified, they are particularly vulnerable. In order to ensure sustainable development and continuing use of the country's water resources, the increasing demand for groundwater needs to be monitored and regulated on the basis of an overall assessment that includes the quality of groundwater, and not only the quantity (Leyland, 2008; Goldscheider, 2005). Protection measures are indeed generally simpler and less expensive than corrective measures with regard to groundwater pollution (Margane, 2003). Therefore, the use of groundwater in Palestine is regulated: licenses are required for drilling of – and extraction from – boreholes or wells (Isaac et al., 2013).

Another problem is the pressure from wastewater on the aquifer, which intensified by the large amount of raw wastewater disposal in the West Bank without adequate and proper environmental and health protection considerations (Al-Khatib et al., 2003; Anayah, 2006). The problem with pollution is that it does not stop at damaging the water environment only;

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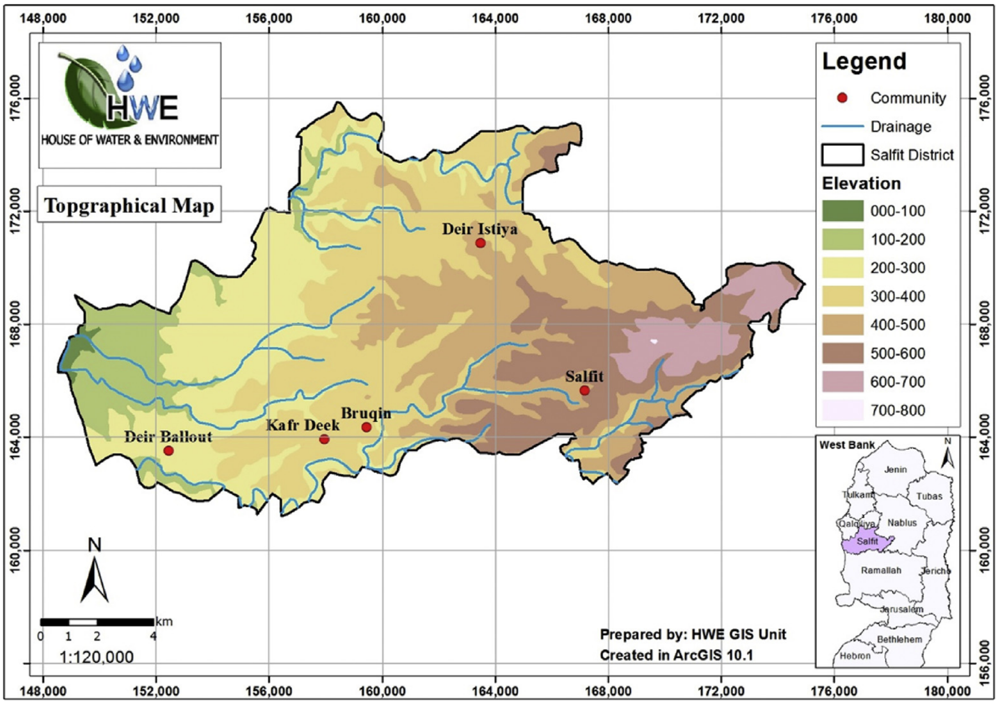

Fig. 1. Topographic and drainage map of Salfit District.

it also causes great health risk impacts associated with microbial (parasites, bacteria, viruses,) and chemical (disinfection by-products, pesticides, metals, etc.) contaminants (Al-Khatib et al., 2008). Contaminations in water used for irrigation can also affect agricultural products (Al-Khatib et al., 2009; Al-Khatib and Abu-Hejleh, 2011).

Control of water-related health risks requires a view that links water management and sanitation to public health in development projects (Shomar, 2011; Tamas et al., 2013; WHO and UNICEF, 2012).

It was noted that improvements in the quantity of water use have an impact on the water washed diseases, and diseases which mainly spread when not enough water is available to maintain a good hygiene (Al-Khatib and Arafat, 2009; Shamsu-Deen, 2013).

Within the scope of this problem and needs, the objectives of this paper are to study the impact of pollution on the groundwater resources of the Salfit District; to develop vulnerability, hazard and risk maps in order to protect the groundwater environment in the study area from pollution; and to assess the health risk impacts of the pollutants on the residents of the district.

1.1. The study area

The study area is the Salfit District which is located in the northern part of the West Bank of Palestine. It is generally characterized by rich groundwater resources, rocky topography, vast tracts of fertile land, and numerous religious and archeological sites. Some agricultural and industrial activities are also present. The topography is characterized by gentle slopes with an elevation ranging between 100 an 700 masl. The slope starts in the east and dips toward the west toward the Mediterranean Sea. There are several major drainage systems; all of them run toward the west as shown in Fig. 1.

The Salfit District is highly influenced by the Mediterranean climate, characterized by dry, hot, long summers and rainy, cool, short winters. Rainfall takes place normally between November and May. The distribution of rainfall is strongly dependent on the topography where it rains more in the mountains and hills. The average rainfall in Salfit City is 637.5 mm/year (PCBS, 2007a). Moreover, there are between 40 and 70 rainy days per year (PCBS, 2007a). The location of Salfit District gives it moderate temperature degrees. The average annual relative humidity in the region is around 62%, and reaches its highest rates during the months of January and February with an average of 67% (PCBS, 2007a). The direction of the wind in the district is South West and North West, with an average velocity of 12 km/h. The average annual evapotranspiration in the district is around 1950 mm/year. Salfit has a relatively low population density, with a total population number of 66,136 (PCBS, 2007a). Average household size is 6, which is about 16% less than the Palestinian national average (PCBS, 2007b).

According to the last demographic study (PCBS, 2007b) on the West Bank, the annual growth rate is about 3%. Salfit District is depending economically on the olive cultivation and stones (for construction). Olive production is the main contributor to the economic development. Any damage of the environment will impact negatively the olive cultivation and will increase the unemployment rate, especially because 11% of the working force is in the agricultural sector. Salfit District

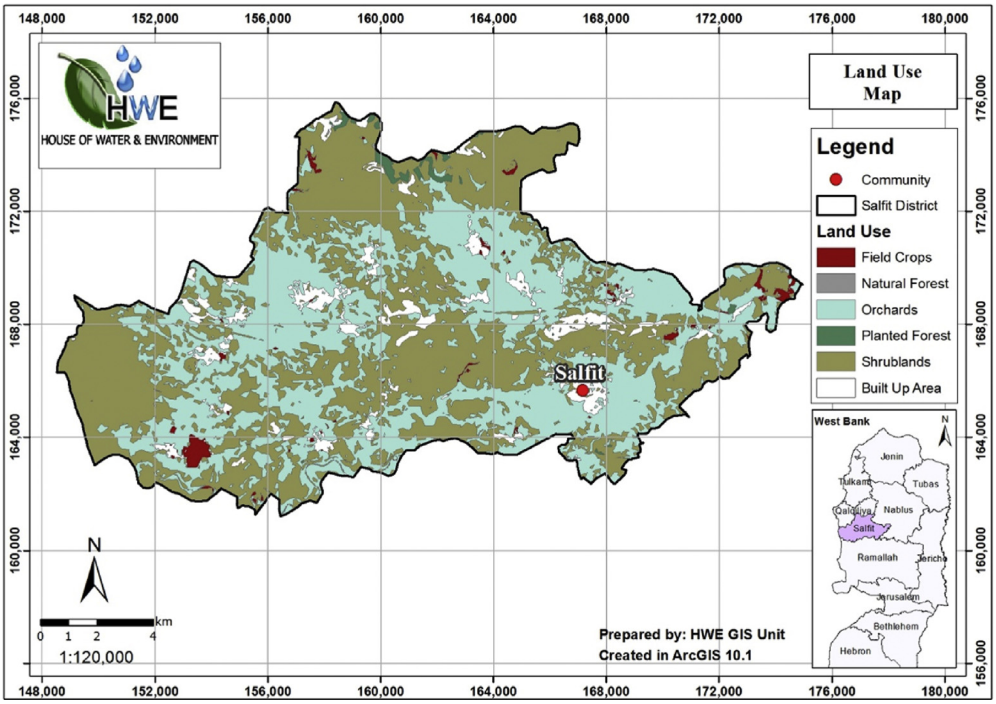

Fig. 2. Land use map of Salfit District.

covers approximately 204 km^2 (PCBS, 2007b). There are Palestinian built up areas, cultivated areas, forests and shrub-lands, as shown in Fig. 2. Fig. 3 (in the supplementary material) shows the distribution of soil types over the district.

1.2. The groundwater environment

The Salfit District covers the biggest aquifer basin in Palestine, which is the Western Aquifer Basin. Two main aquifers are present in this basin: the lower and the upper aquifers. The average thickness of these aquifers ranges between 600 and 900 m. Most of the formations that form these two aquifers outcrop in the Salfit District. Hence, the district is considered as recharging areas for the Western Aquifer Basin. The Salfit District is mainly covered by sedimentary carbonate rocks of the Cretaceous period (Rofe and Raffety, 1965). The outcropping formations are of Albian to Turonian age (Fig. 4); see Fig. 5 (in the supplementary material) for the geological map. Lithological composition of these formations consists mainly of limestone, chalk, marl and dolomite (SUSMAQ, 2003). Karst features develop over time according to limestone and dolomite rock solubility. In these soluble rocks, fracture and fissure apertures enlarge over time creating a network of conduits with a high hydraulic conductivity. The karstification ability in the outcropping rocks of the Salfit District is high. Therefore, any pollution sources on these karstified rocks are going to have severe impacts on groundwater resources.

1.3. Water demand and supply

According to PCBS (2007a,b), the required amount of water for the Salfit District is about 3.6 Mcm/year. More specifically, for the Salfit City the yearly demand is about 0.55 Mcm/year. The city depends on two main local springs “Al Matwi” and “Al Seka”, which supply the city with an average rate of about 0.15 Mcm/year. The other 0.4 Mcm/year has to be purchased from the Mekorot Water Company. From the quantities that the springs supply during the period from 1998 to 2006, the records show that Salfit City still needs further sources to supply water for its population. Because the City relies on local springs for its water supply, these springs have to be protected from pollution.

2. Method of investigation

The investigation of groundwater pollution sources focuses on the contamination risk that may be caused by these sources of pollution on groundwater and the health of the residents in the Salfit District. Water quality sampling campaigns were conducted to collect field data on existing pollution sources. About 7 samples were collected from the main springs in the Salfit District. The locations of these samples are shown in Fig. 6. The samples were analyzed in the laboratory for chemical analysis to detect evidence of pollution and to determine hydrogeochemical processes according to the Durov method.

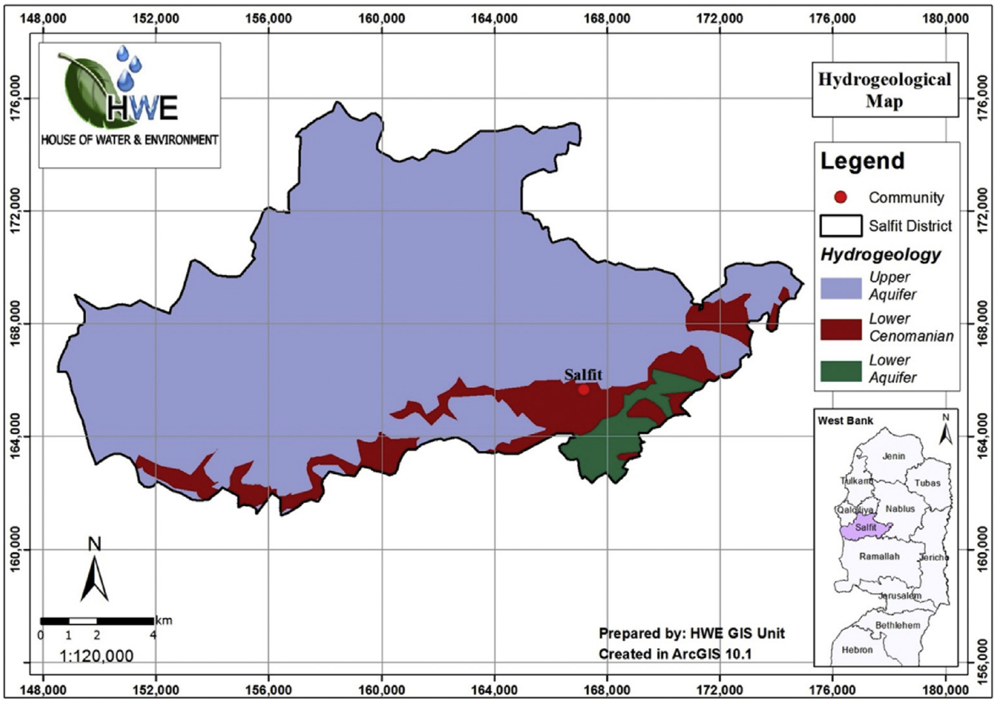

Fig. 4. Hydrogeological map of Salfit District.

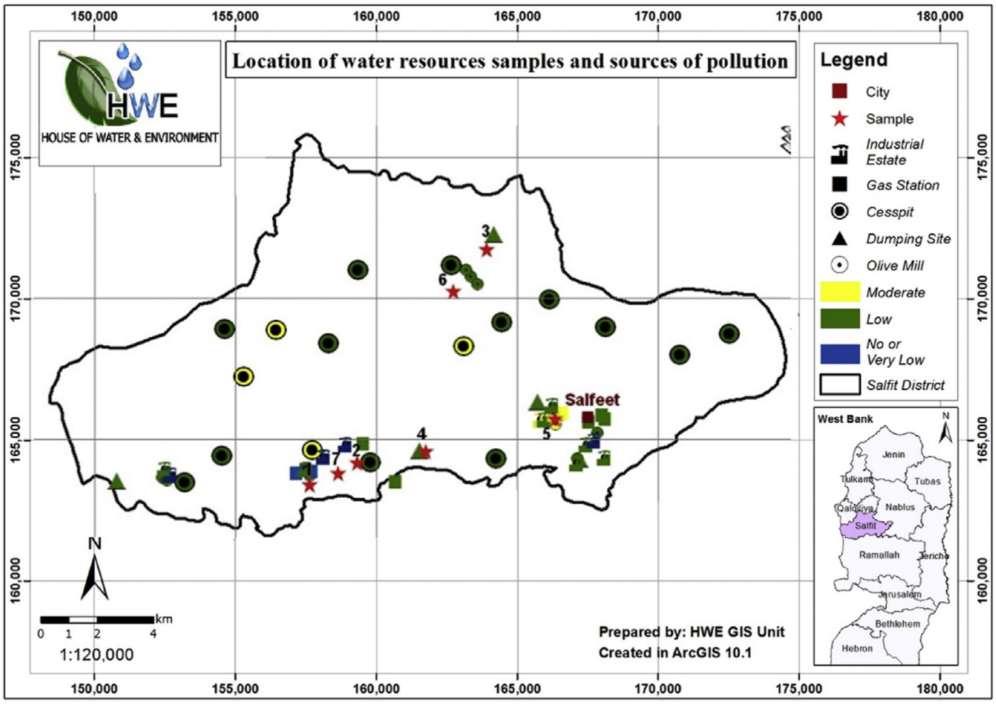

Fig. 6. Location of water resources samples and sources of pollution in Salfit District.

Clinical and household surveys were undertaken to identify hazards to the public health of the residents from pollution. Also 13 water samples were collected into sterile 1000-ml glass bottles at about half meter below water surface level from the cisterns. At each sampling site, the following sampling parameters were obtained: pH, total dissolved substances and electrical conductivity, based on standard procedures (APHA, 1998; Tortora et al., 2003; Al-Salaymeh et al., 2011). The same meters and equipment that were presented by Al-Salaymeh et al. (2011) were used for those measurements. Additional

Table 1
Hydrogeological factors for aquifers in Salfit District (Abu Sa'ada et al., 2003).

Geological formation	Recharge	Lithology value (*L*)	Fracturing value (*F*)
Lower Aquifer	40% of rainfall	5	0.3
Lower Cenomanian	15% of rainfall	10	5
Lower Cretaceous	10% of rainfall	15	15
Senonian (Aquitard)	0.0	20	25
Upper Aquifer	30% of rainfall	5	0.3

Table 2
Top soil and subsoil effective field capacity and corresponding *T* and *S* values (HWE, 2010).

Soil type	Measured/estimated FC (mm/m)	Value – soil (*T*)	Value – subsoil (*S*)
Terra Rossa, Brown Rendzinas and Pale Rendzinas	446	750	Clay – 500
Brown Rendzinas and Pale Rendzinas	334	750	Calyey loam – 300
Grumusols	460	750	Clay – 500
Brown Lithosols and Loessial Serozems	90–140	125	Slightly clayey sand – 75
Brown Lithosols and Loessial Arid Brown Soil	140–200	250	Loamy – 250
Loessial Serozems	140–200	250	Slightly clay –320

collected samples were sent to the Water Engineering Laboratory at Birzeit University (Birzeit-Palestine), within 24 h of collection, in a chilled-cold box at 4 °C for biological analysis. These water samples were analyzed for Total Coliforms and Fecal Coliforms, Sulfate, Ammonium, Chloride, Phosphorus, Lead, Zinc, Aluminum, Cadmium, Silver, Calcium, Magnesium and Potassium, using standard procedures (APHA, 1998; Tortora et al., 2003; Al-Salaymeh et al., 2011). Also, the evidence of pollution (biological and/or chemical) and associated health problems were identified through water quality analysis (Durov, 1948) and health risk assessment was done using standard statistical software packages and GIS mapping. The GIS maps help to prioritize environmental hazards with respect to groundwater vulnerability (i.e., through risk analyses). In particular, a vulnerability map was developed to display the sensitivity of the natural ground cover in Salfit to pollution. A hazard map was developed to classify all pollution activities in the Salfit District, and a risk map was developed from the overlay process of both the hazard and vulnerability maps to show the areas of greatest risk.

2.1. Vulnerability assessment using the PI method

Different methods have been used for vulnerability mapping of groundwater such as DRASTIC (Aller et al., 1985), GOD (Foster, 1987), PI method of European COST Action 620 (Zwahlen, 2003), Ordinal Logistic Regression (Twarakavi and Kaluarachchi, 2005) and a modified DRASTIC method (Gomezdelcampo and Dickerson, 2008). The PI Method for vulnerability assessment was selected due to its suitability for the karst aquifers dominant in the Salfit District. This method was also used before by different authors (Goldscheider et al., 2000; Goldscheider, 2002; Ravbar and Goldscheider, 2007).

The PI Method uses GIS techniques to map groundwater vulnerability in karst aquifers (Nazal, 2007). It accounts for the Infiltration conditions (I-factor) and the Protective cover conditions (P-factor). The first factor accounts for lithology, fractures, soil and subsoil classes, field capacity of the unsaturated zone, recharge from infiltrating water and aquifer hydraulics of being confined or unconfined. The second factor (the I-factor) reflects the infiltration conditions including where the surface water is concentrated. The P-factor points out the effectiveness of the protective cover (Zwahlen, 2003). It is based on Eq. (1) (Zwahlen, 2003):

$$P_{TS} = R\left[T + \left(\sum_{i=1}^{m} S_i M_i\right) + \left(\sum_{j=1}^{m} B_j M_j\right) + A\right] \tag{1}$$

where P_{TS} = the total protective function based on scores; T = the score for the field capacity (%) of the top soil; S = the score of the type of subsoil; M = the thickness (m) of each stratum; B = the bedrock score which equals LF; L = the lithology score; F = the fracturing score; R = the recharge factor based on recharge value in mm/year; A = a score given to the aquifer type (confined or unconfined).

The P-factor is considered very low or low or medium or high or very high if P_{TS} scores are in the ranges 0–10 or 11–100 or 101–1000 or 1001–10,000 or >10,000, respectively.

The surface and subsurface soil, lithology, and fracturing characteristics of the study area of Salfit were identified as presented in Tables 1 and 2. The dominant flow for different soil types and other parameters were also prepared for the construction of the I-factor and are presented in Tables 3–5 (Tables 4 and 5 are presented in the supplementary material).

In essence, the I-factor illustrates the degree that the lateral influxes of fluids can bypass the protective cover. Such flow is considered of great potential of polluting karst groundwater with strong concentration of pollutants. The effect of a sinking stream is minimized if the underlying geological formation is of a very low permeability such as Senonian formation. In general, forest cover augments infiltration, whereas agricultural areas help produce surface runoff (Nazal, 2007). The I-map was prepared by combining the I-factor derived by intersecting land use, slope gradient and dominant flow process evaluated

Table 3
Dominant flow for different soil types of study area (HWE, 2010).

Soil type	Dominant flow	Flow type
Terra Rossa, Brown Rendzinas and Pale Rendzinas	Hortonian surface flow	F
Brown Rendzinas and Pale Rendzinas	Infiltration and subsequent percolations	A
Grumusols	Hortonian surface flow	F
Brown Lithosols and Loessial Serozems	Saturated surface flow	D
Brown Lithosols and Loessial Arid Brown Soil	Saturated surface flow	D
Loessial Serozems	Saturated surface flow	D

Table 7
π-Classes for the vulnerability map (Zwahlen, 2003).

Color	Vulnerability Map (Vulnerability of GW)		P- Map (Protection Cover)		I – Map (Degree of Bypassing)	
	Description	π- factor	Description	P – factor	Description	I – factor
Red	Extreme	0-1	Very low	1	Very high	0.0 – 0.2
Orange	High	> 1-2	Low	2	High	0.4
Yellow	Moderate	>2-3	Moderate	3	Moderate	0.6
Green	Low	>3-4	High	4	Low	0.8
Blue	Very low	>4-5	Very high	5	Very low	1.0

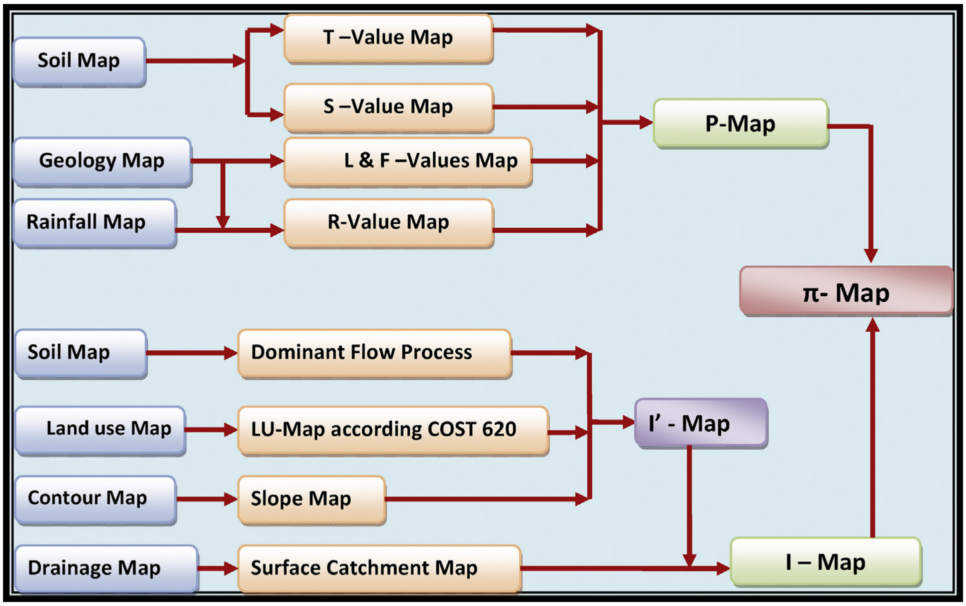

Fig. 7. Flow chart for constructing PI-map (Zwahlen, 2003).

under the surface catchment map. The dominant flow process depends on the permeability of top layers including soil (Mimi and Assi, 2009). For some soil types, values of permeability have been estimated, for the other types the determination of dominant flow was based on the local soil and geological experts.

The surface catchments in the Salfit District were identified by using GIS and digital elevation maps showing all wadis. Table 6 (in the supplementary material) shows the I-factors used for these conditions.

The generated vulnerability map illustrates the spatial distribution of intrinsic vulnerability and the natural protection of the uppermost aquifer only. It should be noted that the protection factor π is obtained by multiplying the P and I factors: $\pi = PI$. Then five classes are used on the generated maps. These classes are symbolized by five colors from red (high risk) to blue (low risk) (Nazal, 2007) (Table 7).

Table 8
Classification of hazards for groundwater protection purposes (Zwahlen, 2003).

Number	Level I categories of hazards	Level II categories of hazards
1	Infrastructural development	
1.1		Waste water
1.2		Municipal waste
1.3		Fuels
1.4		Transport and traffic
1. 5		Recreational facilities
1. 6		Diverse hazards
2	Industrial activities	
2.1		Mining (in operation and abandoned)
2.2		Excavation sites
2.3		Oil and gas exploration
2.4		Industrial plants (non-mining)
2.5		Power plants
2.6		Industrial storage
2.7		Diverting and treatment of waste water
3	Livestock and agriculture	
3.1		Livestock
3.2		Agriculture

Fig. 7 shows a flow chart on how the PI(π) map was prepared. Thematic maps are developed using ArcGIS software package and used as described in Zwahlen (2003).

2.2. Hazard analysis

Hazard in this research is defined as a potential source of contamination resulting from human activities taking place mainly at the outcrops of the geological formations.

A hazard assessment considers the potential degree of harmfulness for each type of hazard. It is determined by both the quantity of harmful substances and the toxicity, which may be released as a result of a contamination event. Hazards should be classified according to the type of land use, i.e., infrastructural, industrial and agricultural activities (Table 8). These main categories are proposed as Level I Categories of Hazards in the Hazard Inventory. The proposed Level II Categories make use of additional criteria, which distinguish between hazards according to the main source (solid or liquid contaminants) of possible groundwater contamination, or else refer to types of industrial or agricultural activities with their corresponding spectrum of possible pollutants.

The main criteria for weighting different hazards that concern the toxicity of relevant substances associated with each type of hazards can be found in Zwahlen (2003). The weighting values vary between 10 (lowest hazard) and 100 (highest hazard).

Each hazard category will depend mainly on the variable quantity (Qn) of harmful substances. Therefore it is better to assign weighting values between 0.8 and 1.2 in order to indicate the level of toxic substances compared with the general average. Apart from the type and quantity of harmful substances associated with a hazard, the technical status, level of maintenance, surrounding conditions and security measures are important factors when assessing the probability that a real contamination of groundwater may occur. This likelihood has to be taken into account whenever the total, combined hazard level, expressed by the hazard index (HI), is to be estimated. This hazard index describes the degree of harmfulness of each hazard. For its calculation the following formula is recommended by Zwahlen (2003):

$$\mathrm{HI} = (H)(\mathrm{Qn})(\mathrm{Rf}) \tag{2}$$

where HI = the hazard index; H = the weighting value of each hazard; Qn = the ranking factor (0.8–1.2); and Rf = the reduction factor which provides an assessment of the probability for a contamination event to occur. If no information on the above mentioned factors is available, then Rf = 1. When the value is set to zero, then there is no hazard of groundwater pollution, but when the value is 1 it is difficult to reduce the likelihood of an impact to the groundwater. Table 9 shows the colors representing the potential degree of harmfulness following that Hazard Index: blue represents no or a very low hazard level; red is a very high hazard level. Table 10 shows the Hazard Index Classes.

Then a hazard map can be developed to show the spatial distribution of the hazards.

2.3. Risk assessment

The risk of polluting the groundwater environment is reliant on intrinsic vulnerability of groundwater to pollution, the hazard of the potentially polluting activity and the potential consequences of the pollution event. Achieving groundwater protection requires an assessment of the risks posed from existing and future human activities, together with responses to the risk in the form of measures designed to mitigate and manage the risk.

Table 9
Hazard index and hazard index classes' colors (Zwahlen, 2003).

Hazard Index	Hazard Index Class	Hazard Level	Colour
0 - 24	1	no or very low	blue
> 24 - 48	2	low	green
> 48 - 72	3	moderate	yellow
> 72 - 96	4	high	orange
> 96 - 120	**5**	**very high**	**red**

Table 10
Hazard Index and the hazard index class (Zwahlen, 2003).

Code	Hazard	HI	Hazard Index class
Infrastructure development			
1.1.4	Septic tank, cesspool, latrine	36–56	2&3
1.1.9	Wastewater discharge into surface water courses	25–54	2&3
1.2.1	Garbage dump	32–48	2
1.3.6	Gasoline Station	20–55	1&2&3
1.4.1	Roads, unsecured	32–40	2
1.6.5	Military installed and dereliction (Settlements)	45–82	2&3&4
Industrial activity & livestock			
2.2.3	Quarry	20–30	2
2.4.10	Food Industry, Olive Mill	36–54	2&3
3.1.3	Factory farm (Slaughter house)	54	3

Table 11
Classification of the risk concerning the classes of the vulnerability and the hazard map (Zwahlen, 2003).

π- factor	HI	1/HI	π. (1/HI)	Risk Class	Risk Level	Color
4-5	0-24	> 0.042	> 0.167	1	no or very low	**Blue**
3-4	24-48	0.042-0.021	0.167-0.063	2	low	**Green**
2-3	48-72	0.021-0.014	0.063-0.028	3	moderate	**Yellow**
1-2	72-96	0.014-0.010	0.028-0.010	4	high	**Orange**
0-1	96-120	< 0.010	< 0.010	5	very high	**Red**

The calculation of the Risk Intensity Index (RII) may consider the hazard and vulnerability indices. The advantage of this procedure is that smooth values (not classes) can be used, resulting in infinitely variable risk values. The RII values can be determined by Eq. (3):

$$\mathrm{RII} = \left(\frac{1}{\mathrm{HI}}\right)\pi \tag{3}$$

where RII = risk intensity index; HI = Hazard Index; π = PI-factor (index for intrinsic vulnerability).

By superimposing the vulnerability and hazard maps, the risk of groundwater pollution map can be developed after applying Eq. (4):

$$R = \left(\frac{1}{\mathrm{HI}}\right)\pi \tag{4}$$

where R = risk value; HI = Hazard Index; π = PI-factor (vulnerability).

The proposed risk assessment is classified taking into account the classes of the vulnerability and the hazard index (Table 11).

3. Results and discussion

3.1. Vulnerability, hazard and risk analysis

The vulnerability map of the Salfit District is shown in Fig. 8. This figure indicates clearly that most of the Salfit District ranges from moderate to very high potential to be vulnerable to pollution. This means that treatment of the pollution should

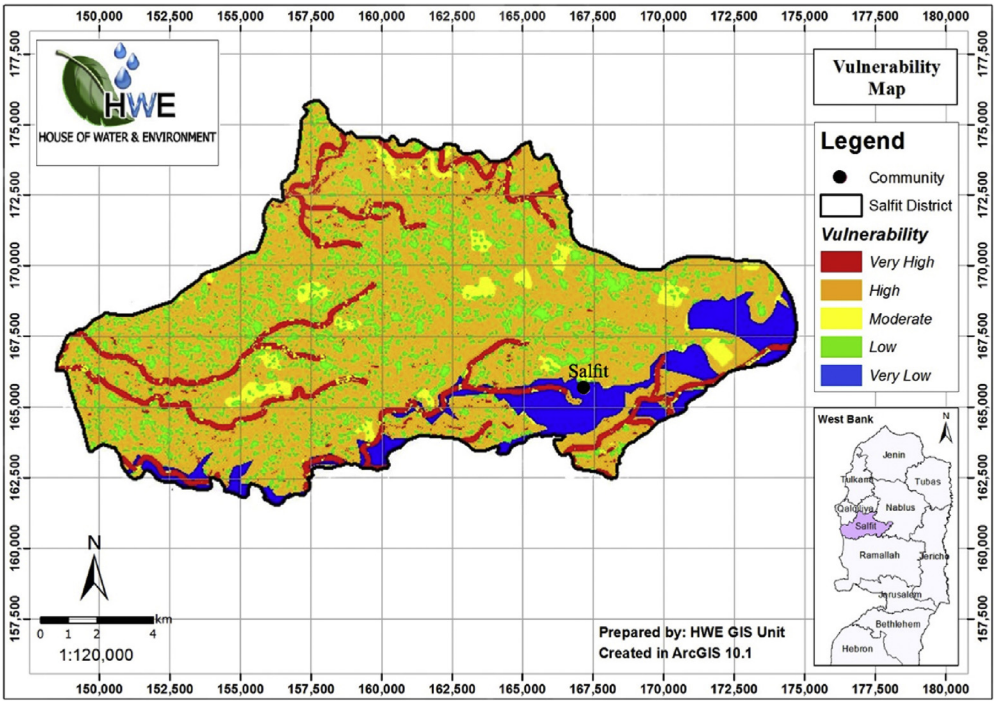

Fig. 8. Vulnerability map of Salfit District according to the PI method.

be considered as very important. The map also shows that the wadis have a very high potential to be vulnerable to pollution of the groundwater resources. This is because these wadis receive raw sewage instead of freshwater. The raw sewage is dumped by settlements and villages into the wadis, causing extreme threat to the purity of the groundwater resources and to the health of the people who utilize these resources. After the analysis of the final vulnerability map (Fig. 8), it was found that 8.6% of the study area is classified as very high, 63.9% as high, 4.3% as moderate, 14.6% as low, while 8.6% as very low. Hence, the Salfit District can be classified as highly vulnerable.

Fig. 9 shows all point sources of groundwater pollution in the Salfit District. A point source of pollution occurs when pollutants are discharged directly into a groundwater aquifer. Point-source pollutants in groundwater aquifers are usually represented by plumes that have the highest concentrations of the pollutant nearest the source and weak concentrations of pollutants further away from the source.

Line sources such as raw sewage in wadis are the main line source in the project area. The diffuse sources of pollution (such as industrial waste, dump sites, landfills, olive mills and cesspits) are also a main reason to pollute Salfit's groundwater. Wastewater infiltrates from these sources to the groundwater with high concentrations, contaminating springs and groundwater aquifers.

It is estimated that 50% of the consumed water in the rural area is discharged to the cesspits, and because each household has its own cesspits, the whole village (built up area) is considered as one cesspit, and treated as diffusive source. For solid waste investigation, the Salfit District has seven dumping sites and they cause a real threat to the groundwater environment because of the random disposal of their leachate. This resulted in raw sewage that is discharged directly to wadis. The wastewater from most factories in the district has no treatment practice for their effluent; these industries are mainly olive mills, food factories, milk and yogurt factories, a single slaughter house in the district, concrete and masonry factories and a number of stone quarries. Based on the method of Zwahlen (2003), and the data collected from the field surveys, Table 10 shows the hazards found for the Salfit District with their possible ranges of the HI and the HI class, taking into account the ranking and reduction factors. Most of the HI values vary between two classes. The hazards in the district represent HI classes ranging from 2 to 3, therefore being low to moderate.

The above data were integrated to generate unclassified (Fig. 10) or classified (Fig. 11) hazard maps (based on HI computation).

Following the Table 11 classification, a hazard classified as low or very low could produce a "high" or even a "very high" risk to groundwater if the vulnerability is very high. In contrast, a hazard classified as high does not produce a "very high" risk when vulnerability is low as the risk classification in this case depends strongly on the vulnerability. In the risk map of the Salfit District, the roads and sewage wadis were given 10 m buffer zones. Then, the hazard map was converted to a grid map where each cell has its value of (1/HI), then multiplied with the same cell which has its own π-value. Hence, the final risk map is a grid map with a cell size of (20 m × 20 m) as shown in Fig. 12.

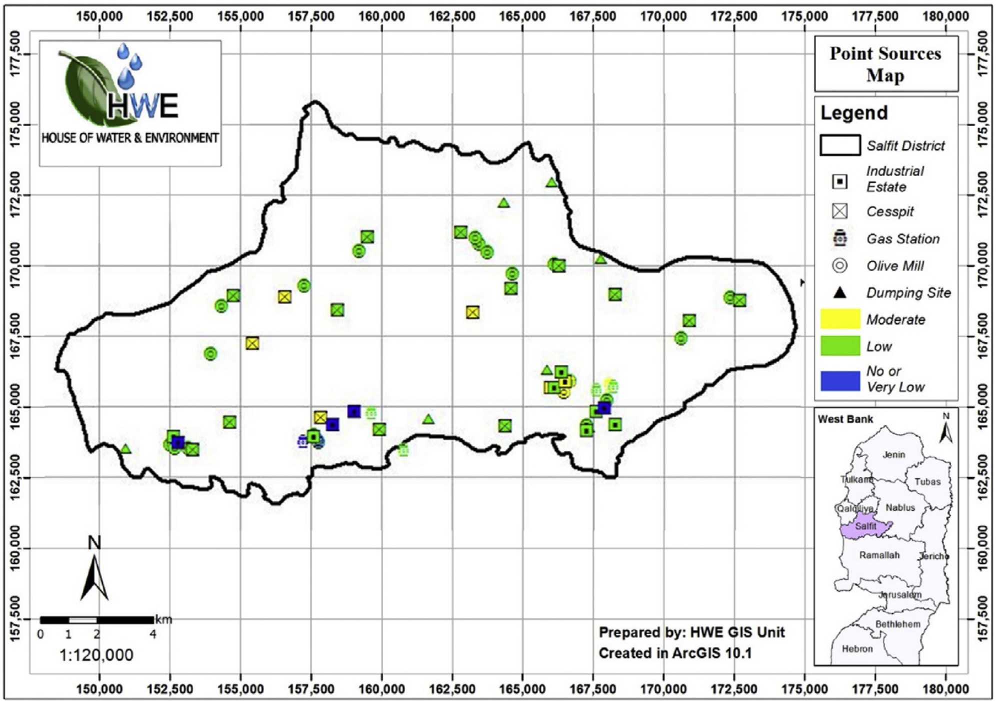

Fig. 9. Point sources in Salfit District.

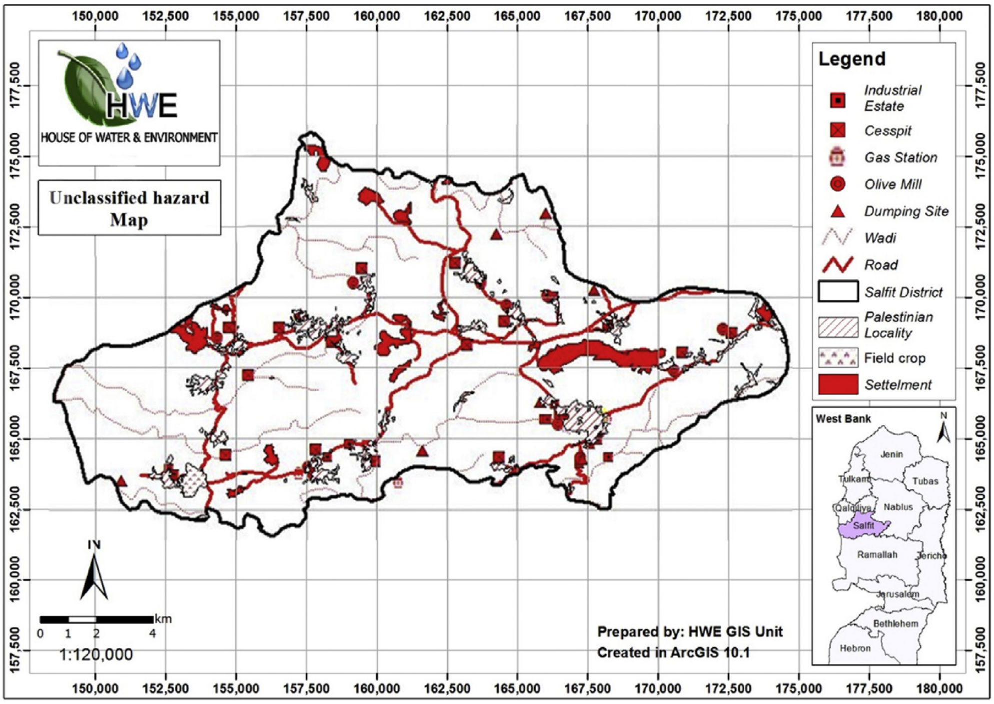

Fig. 10. Unclassified hazard map in Salfit District.

While the hazards occurring in this area are in general of low to moderate levels, with general hazard classes of 2 and 3, none of the hazards were classified as high, except for the Barqan settlement. The latter is an industrial one, with a hazard class of 4. The study of the risk map shows that 9% of the study area is classified as moderate risk, 45% as low, while the remaining 46% of the area has a very low risk. In spite of the high vulnerability in the areas of some roads and drainage wadis, there is a relatively moderate hazard level, yet this leads to a high risk level.

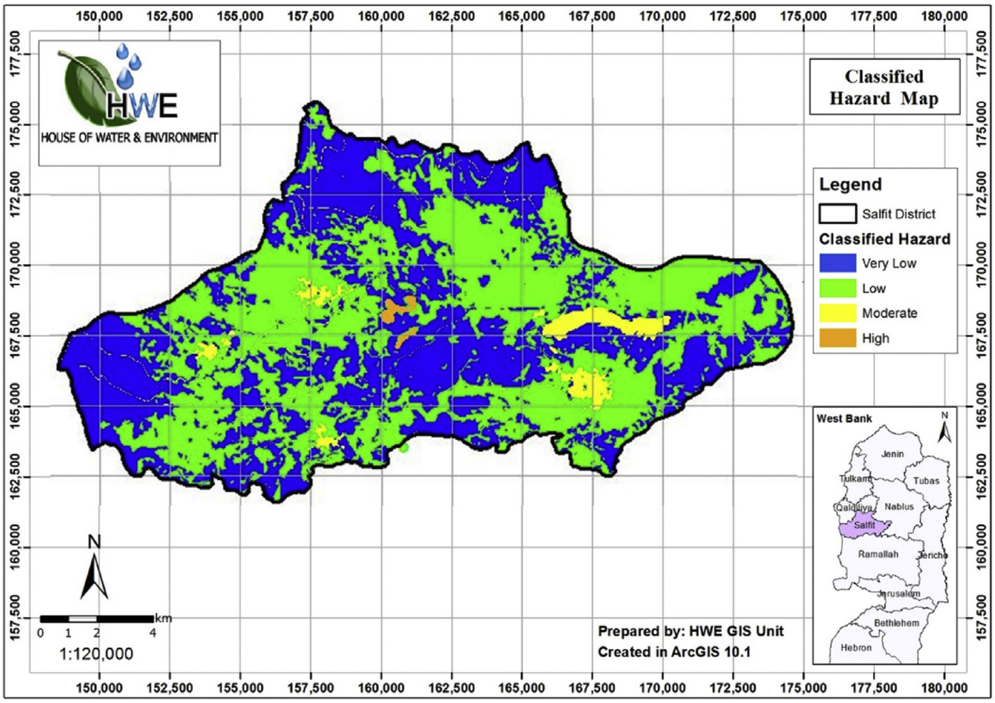

Fig. 11. Classified hazard map in Salfit District.

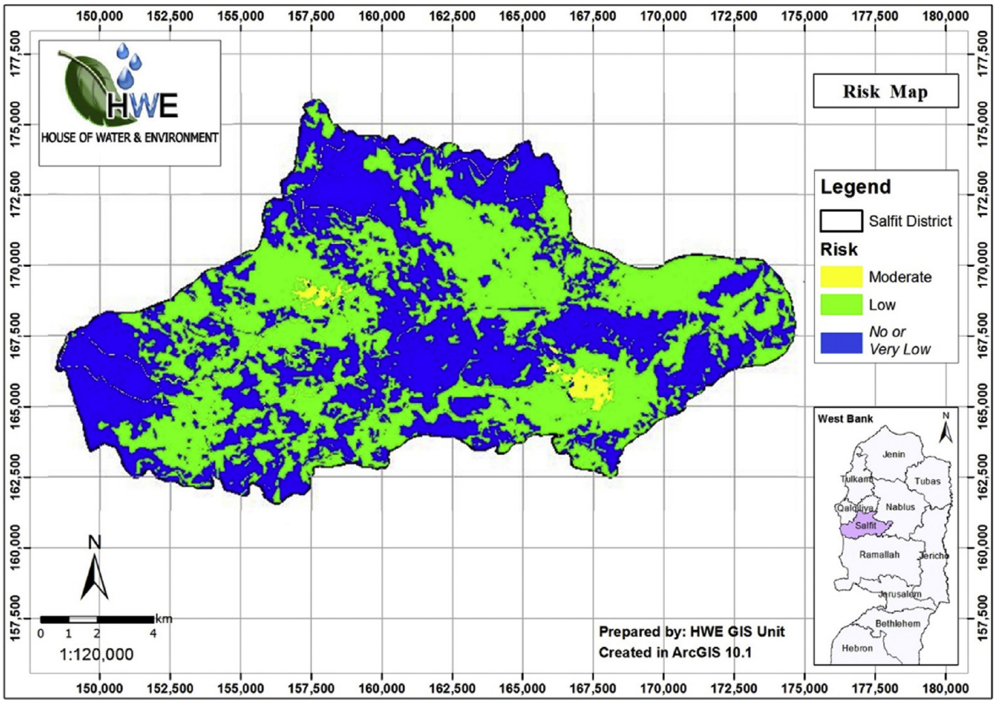

Fig. 12. Risk map of Salfit District.

3.2. Water quality analysis and health risk assessment

The laboratory results of the 90 water supply samples for free chlorine residual (FCR), total *Coliforms* (TC) and fecal *Coliforms* (FC) show that for FCR, 58.9% and 41.1% of the samples have a concentration between 0.2 and 0.8 ppm and less than 0.2 ppm respectively. This means that only 58.9% of the drinking water samples have an acceptable disinfected drinking

Table 12
Physiochemical analysis of the cistern water.

Physiochemical character	Readings range	Readings mean	PSI guidelines	WHO (2004) guidelines
pH	7.22–8.5	7.75	6.5–8.5	6.5–8.5
Sulphate (ppm)	1.3–11.7	5.88	200	200
Conductivity ($\mu S\,cm^{-1}$)	152–1169	584	Up to 2000	Up to 2000
Ammonium (mg/l)	0.2–9.2	1.53	NA [a]	NA
Chloride (mg/l)	78–143.3	128.8	Up to 250	Up to 250
Phosphorus (mg/l)	0–6.1	0.49	NA	NA
Lead (mg/l)	0–0	0	NA	Up to 0.01
Zinc (mg/l)	0–0	0	NA	Up to 5
Aluminum (mg/l)	0.0033–0.022	0.01	Up to 0.2	Up to 0.2
Cadmium (mg/l)	0–0	0	Up to 0.005	NA
Silver (mg/l) Silver (mg/l)	0–0	0	Up to 0.01	NA
Calcium (mg/l)	16–100	69	Up to 100	Up to 100
Magnesium (mg/l)	8–50	25	Up to 100	Up to 100
Potassium (mg/l)	0–0	0	Up to 1.0	Up to 1.0
Total dissolved solids (mg/l)	75–565	287	Up to 500	Up to 500

[a] NA = not available.

water within the limits of standards. Also, it is found that 25% of the samples have TC between (51–50,000)/100 ml, and 75% have TC > 50,000/100 ml. It was also found that 94.6% of the samples with FCR (between 0.0 and 0.1 ppm) were contaminated with FC.

Table 12 summarizes the physiochemical analysis of the cistern water. It is found that concentrations of all heavy metals distributed in potable water samples are zero for Cd and Ag or as low as 0.0015 mg/l for Zn and 0.0033 mg/l for Al. The mean value of EC is 584 μS/cm, 68.9 mg/l for Ca and 28 mg/l for Mg, which all fall into the range of the WHO standards. The highest concentration of NH_4-N (9.2 mg/l) is found in Kafrad Dik. This value exceeds the values proposed by the WHO water quality standards of 0.2 mg/l. Elevated ammonia concentrations could cause taste and odor problems. Ammonia contamination can arise from cement mortar pipe linings, or from animal waste, sewage, or bacterial pollution (WHO, 2004).

The mean PO_4-P concentration exceeds the WHO standards for 5 out of 6 samples tested in the Salfit District. Such high values can be related to agricultural activity and/or organic pollution. Chloride concentrations range from 78 mg/l to 143.3 mg/l. Chloride concentrations higher than 200 mg/l may cause unpleasant taste of water (Versari et al., 2002). Sulphate concentration in water samples ranges from 1.2 mg/l to 11.7 mg/l. According to the WHO guidelines, none of the tested water samples exceed the sulphate concentration limit for drinking water. In all samples, Zn is found at very low concentrations (=<0.015 mg/l) and meets the requirements set by the WHO drinking water standards.

The Durov diagram was constructed for all water source samples as shown in Fig. 13. The analysis of water source samples shows that the groundwater starts as fresh recharge type (sample 3) of (Ca-HCO_3^-), which is a typical fresh groundwater in the recharge areas of limestone aquifers. Then, as we move downwards, it is clear that the freshwater recharge type mixes with raw waste (samples 6 and 2), as shown by the location in the mixing zone of the Durov diagram. The groundwater at the location of remaining samples has domination of earth alkaline with (HCO_3^-–SO_4^{-2}), (HCO_3^-–Cl) or (SO_4^{-2}–Cl^-), which rise as a result of the raw sewage pollution from villages and settlements. The chemical analysis of the raw wastewater of the settlements shows elevated levels of SO_4^{-2} and Cl^-. In the study area, the wastewater from the settlements is considered as the major source of groundwater pollution. From a source perspective Ca^{2+} is prominent in soil and construction materials, while Cl^-, Na^+ and SO_4^{2-} are principle components of sea salt and raw sewage. SO_4^{2-}, Cl^- and NO_3^- together represent the major ionic derivatives of industrial and traffic emissions (Evans et al., 2006). However, chloride concentrations in excess of about 250 mg/l can give rise to detectable taste in water (WHO, 2004).

About 71.5% and 26.9% of the households in the Salfit District are connected to water and sewage networks respectively. About 42.1% of the interviewees with homes connected to the sewage network reported flooding of sewage, and 83% said that flooding occurred in the summer season. More than half of the respondents reported that there were sewage floods in the streets mainly during the summer.

Self-reported diseases were claimed by some of the interviewees: 24.4%, 46.1% and 34.8% of the interviewees reported eye diseases, diarrhoeal diseases, and vomiting, respectively. Other diseases were reported with fewer percentages: 8.9%, 6.7% 12.8% for skin diseases, hepatitis A and lice respectively. The Ministry of Health directorate reported for the Salfit District in 2005–2007: 80 cases of Hepatitis A, 3 cases of Ascariasis (Round Worm), 478 cases of Amebiasis Trophozoite, 51 cases of

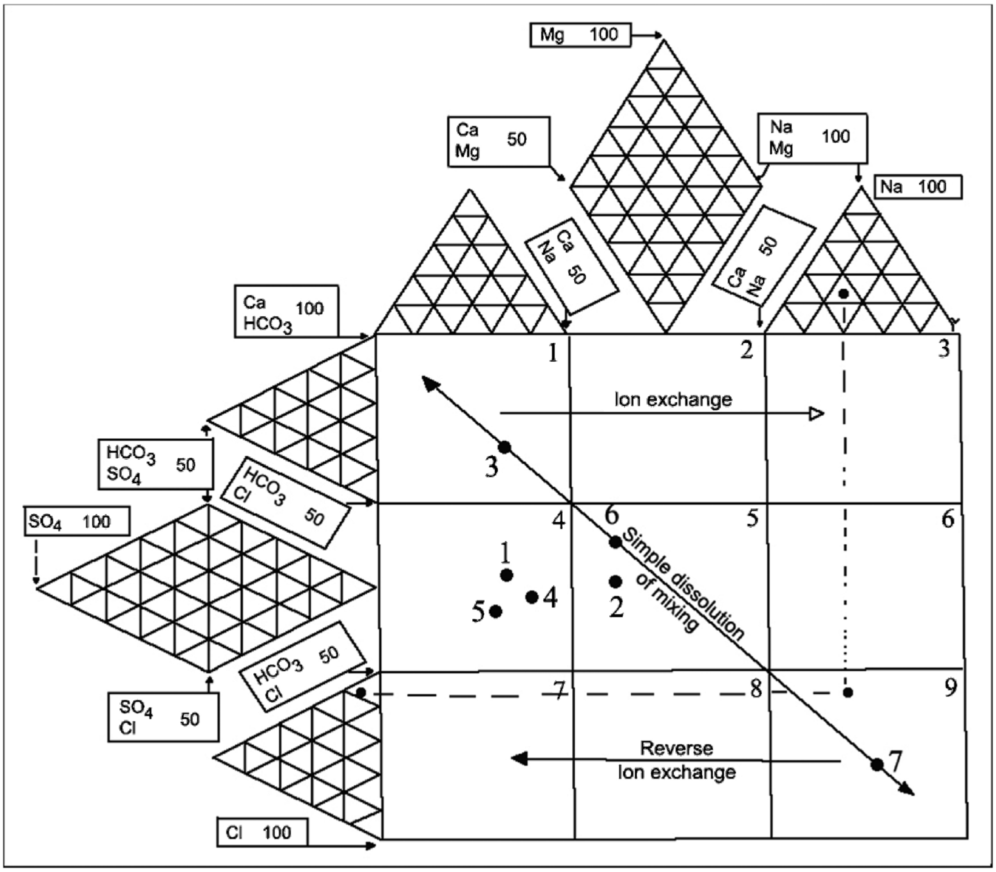

Fig. 13. Durov diagram for the samples of Salfit District.

Scabies, 8 cases of Typhoid and paratyphoid, 1458 cases of Oxyuriasis. It was found that these were water related diseases and that health problems are resulting from contaminated drinking water.

4. Conclusions and recommendations

Salfit sits on the outcrops and recharge areas of the Western Aquifer Basin (WAB), which is one of the main sources of domestic water for Palestinians in the West Bank.

A number of pollution sources including sewage, leachate of solid wastes and industrial wastes have been flowing untreated in the Salfit Aquifer's recharge area for years ultimately percolating into the groundwater since the aquifer is located in a karstified dolomitic limestone. Thus, the groundwater aquifer is directly threatened. Pollution hazards are found throughout the Salfit District largely due to the nonexistence or inadequate infrastructure of sewer networks or treatment plants. In the meantime, the industrial and solid wastes as well as sewage problems in the district remain unresolved and constitute major hazards.

The residents of the Salfit District use the springs and groundwater aquifers for water supply. These sources of water are polluted by sewage, solid and industrial wastes and, therefore, the health of the residents is directly impacted negatively.

Higher levels of total and fecal *Coliforms* in cisterns and networks than that of the WHO limits were detected in the selected communities of the Salfit District. However, *Coliforms* contamination in cisterns was higher than in water networks throughout the study period.

It was concluded that disinfection was almost absent in cisterns, and chlorination processes were quite well implemented by most of the communities that have water network systems. Cross-contamination of pipeline systems may contribute to higher levels of total and fecal *Coliforms* contamination registered for water networks. It was also concluded that the drinking water supplies and resources were contaminated by sewage, which is believed to be behind the spread of some water related diseases such as eye diseases, diarrhoeal diseases in addition to vomiting reported in clinics of the study area.

Very few drinking water samples had values of chemical quality exceeding the WHO drinking water standards, mainly for NH_4-N and PO_4-P.

The vulnerability map shows that 8.6% of the study area is classified as very highly vulnerable to pollution, 63.9% as highly vulnerable, 4.3% as moderate, 14.6% as low, and 8.6% as very low. Hence, the Salfit District in general can be classified as high vulnerable. While the hazards occurring in this area are in general of low to moderate, none of the hazards were classified as high except for the Barqan settlement, which is an industrial one. In terms of risk, it is found that 9% of the study area has moderate risk, 45% low risk, and the remaining 46% of the area as very low risk. In spite of the high vulnerability for the areas around some roads and drainage wadis, there is a relatively moderate hazard level, yet this leads to a high risk level.

Regulations can be written and enforced, which can stop contamination from any pollution source entering into the aquifer. Direct command over companies, factories, individual activities or specific practices can take place by the government to directly control and improve those activities in order to guarantee less impact to groundwater by their effluents. Existing laws and regulations with regard to cleaning up polluted areas must be enforced and applied to industrial facilities, e.g., garages.

Conflict of interest

None declared.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ejrh.2015.07.006.

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